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MRL-TN-526

AUSTRALIAN STRUCTURES RESPONSE EVALUATION: GROUND SHOCK AND AIR BLAST MEASUREMENTS FOR SITE INVESTIGATION SURVEY

Phillip Box

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ABSTRACT

A site investigation survey was conducted during November 1986 as a preliminary requirement for the drafting of a trials plan associated with the proposed Australian Structures Response Evaluation Trials. The site near Woomera, South Australia was formerly used by the European Launcher Development Organization during the 1960's. Ground shock and air blast measurements were conducted during the survey. This report details the instrumentation and the techniques used for making these measurements.

An investigation into the response of the piezoelectric polymer transducers used during the survey is described and the results reported.

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AUSTRALIAN STRUCTURES RESPONSE EVALUATION:
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FOR SITE INVESTIGATION SURVEY

1. INTRODUCTION

A site investigation survey of two disused concrete structures, and their immediate environs, which were used by the European Launcher Development Organisation (ELDO) during the 1960s for launching rockets, was carried out to enable the drafting of a trials plan for the Australian Structures Response Evaluation (ASRE) trials [1]. These trials are to be conducted in 1987-88 under the auspices of TTCP WTP-1 KTA 1-17. The ELDO structures are situated at the north-eastern extremity of Lake Hart, near Woomera, South Australia. The survey team comprised personnel from USA, Canada, UK, and Australia. The investigations were directed by USA personnel. These Laboratories were responsible for the recording and reproduction of ground shock and air blast data.

The measurement of ground shock resulting from the detonation of small, buried explosive charges was attempted to enable the characterisation of the ground shock propagation. Air blast resulting from the detonation of small explosive charges suspended in air was measured to assess the suitability of piezoelectric polymer pressure gauges for air blast measurements during the ASRE trials.

On return to the Laboratories the response of the piezoelectric polymer pressure gauges, supplied by USA personnel, was investigated.

Details of the field and laboratory investigations are presented in this report.

2. FIELD TESTS

Pressure-time histories for five ground shock events and three air blast events were recorded. Six of these events were in the vicinity of the northern site (Launcher A - Fig. 1), where the instrumentation was located in one of the instrument vans.

The remaining two instrumented events occurred at Launcher B where the instrumentation was located in the rear of a four-wheel-drive vehicle.

2.1 Ground Shock Events

Piezoelectric polymer pressure gauges were used to measure ground shock. The gauges were bedded in mud against a rock or, in two cases, against concrete walls and buried at a depth of 0.3 m, the same depth as the explosive charge. Fine sand was compacted around the gauges. This procedure was adopted in an attempt to ensure that the gauges were in intimate contact with the shock propagating medium.

Details of the ground shock events are as follows:

Event G1. 0.9 kg of plastic explosive (PE4) was detonated in silty sand dispersed with sandstone rock at a site approximately 40 m south-east of Launcher A. As depicted in Figure 2, ground shock was measured at distances of 1.5 m and 1.8 m from ground zero (GZ).

Event G2. A repeat of Event G1.

Event G3. 1.4 kg PE4 was detonated in sandy backfill adjacent to the southern side of Launcher B. Ground shock was measured at three positions: two against concrete walls of the launcher, each 2.7 m from GZ, and the third midway between GZ and one wall (Fig. 3).

Event G4. A repeat of Event G1, differing only by the burial of the miniature low noise coaxial cable in a shallow trench for a distance of approximately 3 m from each gauge.

Event G5. 0.9 kg PE4 was detonated in backfill adjacent to the northern side of Launcher B. The backfill was a whitish coloured sand intermixed with large rocks. Ground shock was measured at three positions two at 1.5 m and one at 3 m from GZ (Fig. 4). The miniature low noise coaxial cable from each gauge was buried over a distance of 3 m in shallow trenches.

2.2 Air Blast Events

The polymer pressure gauges were also used to measure reflected air blast from three detonations. The measurement arrangement for Events A1 and A2 was identical, with Event A3 differing only by the use of protection for the cable from each gauge.

For all three events 0.9 kg PE4 explosive charges were detonated at a height of about 1.5 m while suspended midway between two concrete posts, which were approximately 3 m apart (Fig. 5). The pressure gauges were bedded in mud against each post and secured with adhesive tape; the mud was used to avoid air gaps between the gauges and the posts.

The miniature low noise coaxial cable from each gauge was protected during Event A3 by lengths of triangular, slotted timber (Fig. 6) secured against the concrete posts and by burial over a distance of 2 m from the posts.

2.3 Instrumentation

The active element of the piezoelectric polymer pressure gauges (Fig. 7) is a polyvinylidene fluoride polymer. The gauges used for air blast differed from those for ground shock in that they were coated with a layer of polyether imide in an attempt to delay any thermal response. The gauges were calibrated by USA National Bureau of Standards [2,3].

Each gauge was connected to a charge amplifier, Kistler Model 504D, by miniature low noise coaxial cable. The output signals from the charge amplifiers were transmitted to the instrumentation station by conventional coaxial cable (UR70).

The pressure-time histories from both the ground shock and air blast events were recorded on a 7-channel magnetic tape recorder, Teac Model SR-31, using F.M. record/replay modules. The recorder was operated at 152 cm/s giving an effective bandwidth of D.C. to 40 kHz. One channel was used for the recording of time data from a time mark generator, Tektronix Model 2901.

In order to determine shock arrival times an electrical signal (Time Zero) coincident with the detonation of the explosive charge was required. The recording of a time zero (TZ) signal was attempted by attenuating the 150 V firing pulse using a 10 to 1 attenuation probe, BWD Model P32. Delay detonators, with functioning times that were not accurately known, were used to initiate all the explosive charges so the TZ signal proved to be of no use.

For the purpose of preliminary examination of data on site, replay of each channel was performed using a digital waveform recorder, Biomation Model 805, and a conventional CRO. Hard copy was obtained using a Y-t recorder, Yew Model 3066. An instrumentation schematic is shown in Figure 8.

Final reduction of the data was performed at MRL using a computer-based system which has been developed around a Charles River Data System, Model MF211, minicomputer. The data were digitized by means of a digital CRO, Norland Prowler Model N4000X3.

3. FIELD DATA

3.1 Ground Shock

The majority of the records were electrically noisy, the source of which could not be identified with certainty. The records shown in the report have been smoothed digitally. The smoothing process averaged each digital sample with two samples immediately before and after for each of the 4096 samples per record. An example of a pressure-time profile before and after smoothing is shown in Figures 9 and 10. The remainder of the smoothed pressure-time profiles are shown in Figures 11 to 19. Peak pressures as measured from the records are shown in Table 1.

Shock arrival times could not be measured because of the lack of a suitable time zero signal. Instead time intervals between shock arrivals were measured by digitizing two records simultaneously on the dual channel digital CRO. Shock arrivals were taken to be the first discernible pressure change from the base-line. Time intervals are shown in Table 2.

3.2 Air Blast

The pressure data of interest were superimposed on a low frequency negative drift. An attempt was made to correct the data, for the negative drift, using a solid state variable filter (Krohn-Hite Model 3550). The filter was configured as a high pass, fourth order Butterworth filter. It was not possible to correct for the drift in this way without dramatically affecting the amplitude and profile of the data of interest.

The data were therefore corrected by creating a profile of the same shape and amplitude as the low frequency drift using a pulse generator, HP 8012B, and an R-C circuit. It was possible by visual inspection to closely duplicate the profile by adjustment of the R-C time constant, and the risetime and amplitude of the pulse. Again using the dual channel digital CRO this profile was then subtracted from the pressure-time profile. (Although it is considered that this procedure was satisfactory for analysing these records it required visual interpretation of the data and therefore would not be recommended as a normal analytical process.) An example of a pressure-time profile before and after correction is shown in Figures 20 and 21. The remainder of the corrected pressure-time profiles are shown in Figures 22 to 26.

Peak overpressure, positive phase duration and positive overpressure impulse for each event are shown in Table 3.

4. COMMENTS ON FIELD TESTS

4.1 Ground Shock

The ground shock records appear as if they might be inconsistent and thus it is doubtful whether they provide useful records of pressure-time histories. Laboratory tests (Section 5) have shown that the response of the gauges to transients is poor and very much dependent on the mounting technique. It is suspected that parts of the example long time-scale record shown in Figure 27 are spurious signals attributable to the mounting technique used for the field tests.

4.2 Air Blast

The pressure-time profiles exhibited a negative drift which started between 0.85 ms and 1.25 ms prior to the air blast arrival.

These times are similar to a predicted shock arrival time of about 1.2 ms for a 1 kg PE4 charge at a standoff of 1.5 m. The polymer gauges, being only 1.5 m from GZ, would have been affected by optical radiation from the detonation prior to the air blast arrival and, as shown by post-trial experiments (Section 5), this would result in the negative drift exhibited.

5. LABORATORY INVESTIGATIONS

5.1 Response to Pressure Pulse

A piezoelectric polymer gauge was mounted in close proximity to a well characterized piezoelectric quartz gauge, PCB 102A02, to investigate its response to air blast. The quartz gauge was flush mounted in a 450 mm diameter aluminium plate while the polymer gauge was mounted on the surface of the plate using three different methods:

(i) secured with adhesive tape;

(ii) secured with double side foam tape (thickness = 1.6 mm); and

(iii) bedded in heavy consistency silicone.

The pressure sensing elements of the gauges being compared were separated by a distance of 15 mm.

A cap starting pistol was used to generate the pressure pulse. The cap in the pistol was positioned 0.3 m from, and on a line normal to, the surface of the plate (Fig. 28). Use of a starting pistol is a proven method of carrying out a function test on air blast instrumentation. The starting pistol generates a pressure impulse which is fairly repeatable and closely resembles the classical air blast profile. At the distance used here the peak free field pressure produced by the cap is about 10 kPa.

The data from the two types of pressure gauges were acquired simultaneously so direct comparisons can be made. The pressure-time profiles are shown in Figures 29 to 34.

5.2 Response to Optical Radiation

A series of tests was devised to investigate the apparent sensitivity of the polymer gauge to optical radiation, and to ascertain whether this sensitivity could produce a spurious response to a fireball during the detonation of an explosive.

A polymer gauge was positioned, in a darkened room, 0.3 m from an electronic, photographic flash gun (Metz 45CT-5). The flash gun was configured to generate its maximum intensity pulse.

Three filters were chosen to give an indication of the gauge's spectral sensitivity whereby the equivalent pressure indicated by the gauge's response was measured firstly with the radiation unfiltered and then filtered using:

(i) 25 mm thick perspex;

(ii) 50 mm deep copper sulphate solution; and

(iii) a combination of (i) and (ii).

A 13% copper sulphate solution has a spectral transmittance similar to that of a Corning coloured filter, No. 9780 [4]. The spectral transmittance of these media are shown in Table 4 where it will be seen that 25 mm thick perspex has negligible transmittance below a wavelength of 0.38 μm and a copper sulphate solution has little transmittance above a wavelength of 0.62 μm, except between the wavelengths of 1.4 μm and 2.8 μm.

The equivalent pressure-time profiles are shown in Figures 35 to 40. The data obtained for those tests where the copper sulphate solution was not used are shown over two different time windows to show detail of the initial response.

5.3 Explosives Tests

A polymer gauge was bedded in heavy consistency silicone on the concrete floor of an explosive chamber. Explosive charges of 115 g PE4 were detonated while

suspended 0.75 m directly above the gauge. This configuration was chosen to produce approximately the same peak reflected pressures as those measured in the field.

The gauge was subjected to the air blast initially with no protection and then with a covering of three layers of a 12 μm thick aluminised mylar. The combination of three layers of the aluminised mylar had a light transmittance of 0.1%. This was carried out in a attempt to allow the gauge to respond to the air blast but reflect any optical radiation from the fireball. Examples of the pressure-time profiles with and without the aluminised mylar covering are shown in Figures 41 and 42.

6. COMMENTS ON LABORATORY INVESTIGATIONS

6.1 Response to Pressure Pulse

The pressure-time profiles from the quartz gauge show the repeatability of the test configuration. However, the profiles from the polymer gauge are different for each of the mounting techniques used, and all are significantly different from those of the quartz gauge.

6.2 Response to Optical Radiation

It can be inferred from the photographic flash tests that the polymer gauge is sensitive to infra-red radiation since the inclusion of a copper sulphate solution as an infra-red filter reduced the response considerably. However, as the response of the gauge was still significant, it would appear that the gauge is quite sensitive to visible and/or infra-red radiation between 1.4 μm and 2.8 μm.

Further tests were not conducted to fully resolve the spectral sensitivity of the polymer gauges.

6.3 Explosive Tests

The pressure-time profile obtained when the polymer gauge was used without the aluminised mylar covering (Fig. 41) exhibited negative drift prior to the air blast arrival as observed in the field data. The pressure-time profile obtained when the gauge was covered (Fig. 42), however, did not exhibit this drift. The air blast profile though, did appear to have been distorted by the mylar as might be expected.

7. CONCLUSION

The polymer gauges used during the survey, and subsequently tested in the laboratory, have exhibited two main problems: (i) lack of a suitable mounting technique; and (ii) sensitivity to optical radiation.

In light of the difficulty of achieving an acceptable response to air blast it is considered that the measurement of air blast and ground shock using piezoelectric polymer gauges would best not be attempted before an adequate gauge deployment scheme is devised and comprehensive testing is carried out in conditions similar to that in which they are intended to be used.

The laboratory investigations indicate that a metallic coating could reduce the gauges sensitivity to optical radiation.

8. REFERENCES

1. TTCP Technical Panel W-1 (1986) "Terminal Effects Test Plan Woomera Structures (ELDO Site)". Unpublished

2. Davis, G.T. (National Bureau of Standards, United States Department of Commerce) (1986). Unpublished Results

3. Carino, N.J. (National Bureau of Standards, United States Department of Commerce) (1986). Unpublished Results

4. Kodak Publications No. M-28. (1972). Applied Infrared Photography.

TABLE 1

Peak Pressures and Ground Ranges for
Ground Shock Events

	Ground Range (m)	Direction	Peak Pressure (kPa)
Event G1	1.5	N	> 336.*
	1.8	S	> 175.*
Event G2	1.5	N	> 325.*
	1.8	S	123.
Event G3	1.35	N	304.
	2.7	N	65.1
	2.7	W	55.1
Event G4	1.5	N	> 340.*
	1.8	S	NR
Event G5	1.5	NW	219.
	1.5	SE	NR
	3.0	SE	94.6

* Tape Overload

NR - No Record

TABLE 2

Ground Range and Arrival Time Intervals for Ground Shock Events

	Ground Range (m)	Direction	Ground Range Difference (m)	Time Interval (ms)
Event G1	1.5 1.8	N S	0.3	1.0
Event G2	1.5 1.8	N S	0.3	1.8
Event G3	1.35 2.7	N N	1.35	3.0
	1.35 2.7	N W	1.35	4.8
Event G5	1.5 3.0	NW SE	1.5	7.8

TABLE 3

Peak Overpressure, Positive Phase Duration and
Positive Overpressure Impulse for Air Blast Events

	Peak Pressure (kPa)	Positive Phase Duration (μs)	Positive Overpressure Impulse (Pa s)
Event A1	1880*	214	209*
	2380*	344	359*
Event A2	2390	218	260
	4600	206	416
Event A3	3430	407	416
	3430	809	1210

* Tape Overload

TABLE 4

Percentage Transmittance

Wavelength (μm)	25 mm Perspex (%)	Corning Glass No. 9780 (%)
0.20	0.0	0.0
0.24	0.0	0.0
0.26	0.0	0.0
0.28	0.0	0.0
0.38	5.7	59.0
0.40	79.3	72.5
0.42	83.3	77.0
0.44	84.1	80.1
0.46	84.5	82.3
0.48	84.9	83.9
0.50	85.1	84.3
0.52	85.1	82.4
0.54	85.1	75.6
0.56	85.3	61.5
0.58	85.3	41.4
0.60	85.5	21.5
0.62	85.5	8.0
0.64	85.9	2.1
0.66	86.1	0.3
0.68	86.3	0.0
0.70	86.3	0.0
0.72	85.6	0.0
0.74	86.1	0.0
0.80	87.7	0.0
1.0		0.0
1.2		0.0
1.4		1.8
1.6		13.1
1.8		31.7
2.0		44.0
2.4		44.0
2.6		28.0
2.8		6.0
3.0		0.0
4.0		0.0
5.0		0.0

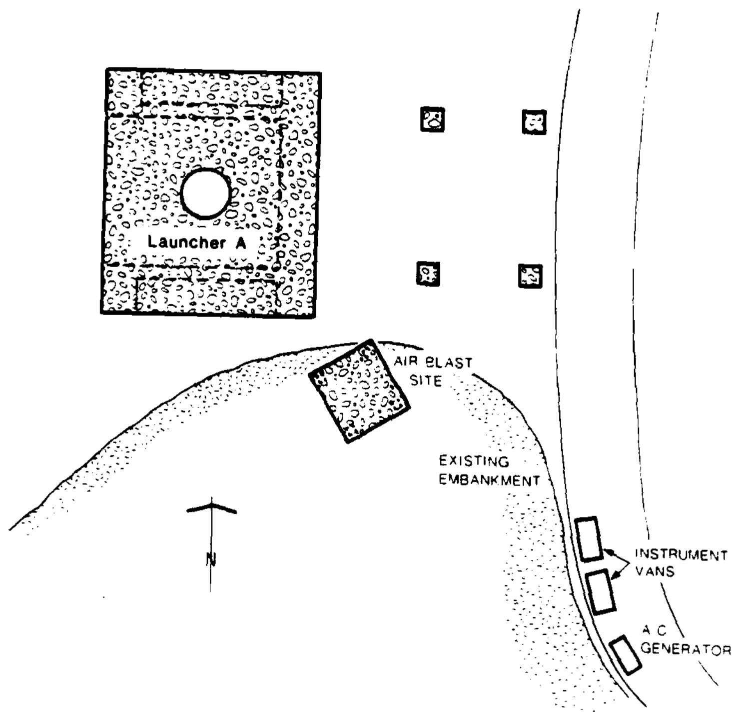

FIGURE 1 Launcher A trial site layout.

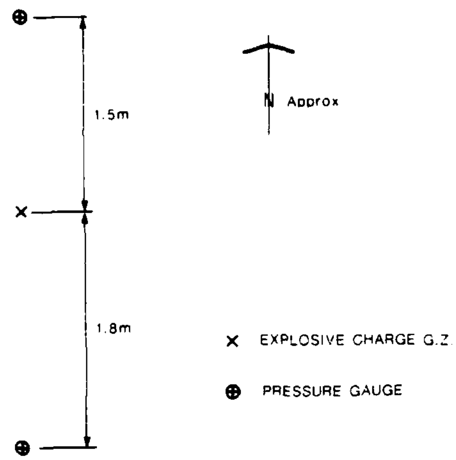

FIGURE 2 Field layout of pressure gauges; for ground shock Events G1, G2 and G4.

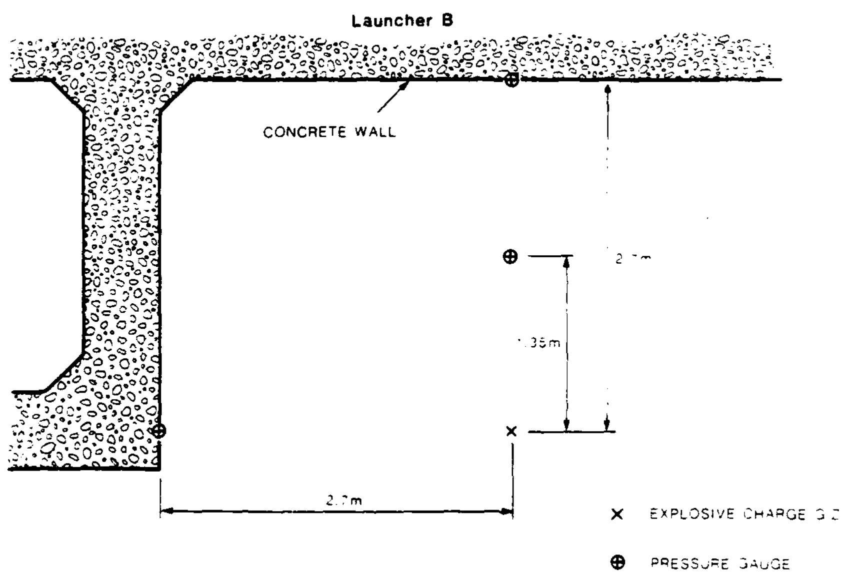

FIGURE 3 Field layout of pressure gauges; for ground shock Event G3.

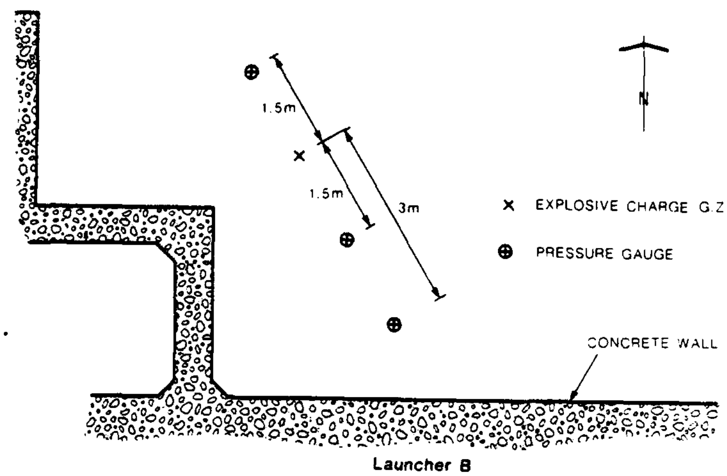

FIGURE 4 Field layout of pressure gauges; for ground shock Event G5.

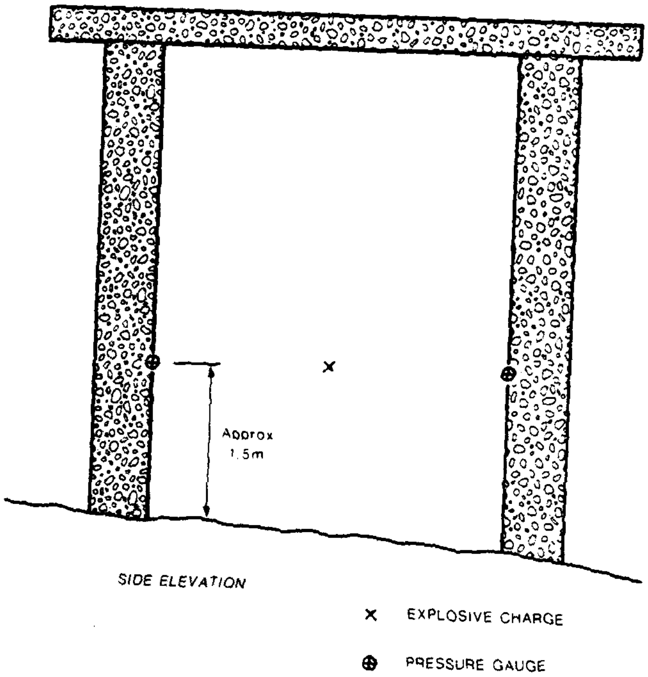

FIGURE 5 Location of pressure gauges; for air blast Events A1, A2 and A3.

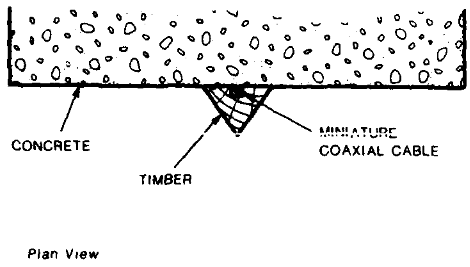

FIGURE 6 Detail of timber cable protection.

FIGURE 7 Piezoelectric Polymer Pressure gauge.

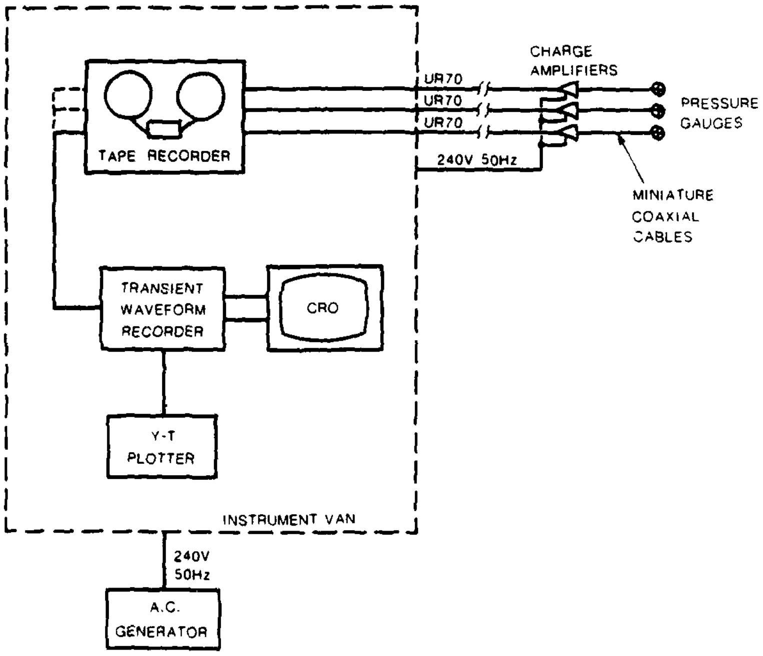

FIGURE 8 Instrumentation schematic.

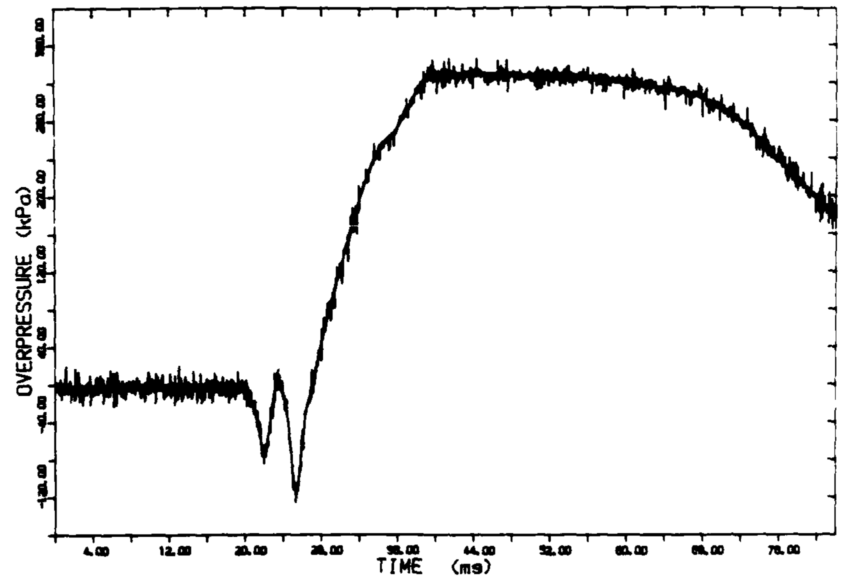

FIGURE 9 Pressure-time record from ground shock Event G1. d = 1.5 m (N). Record clipped.

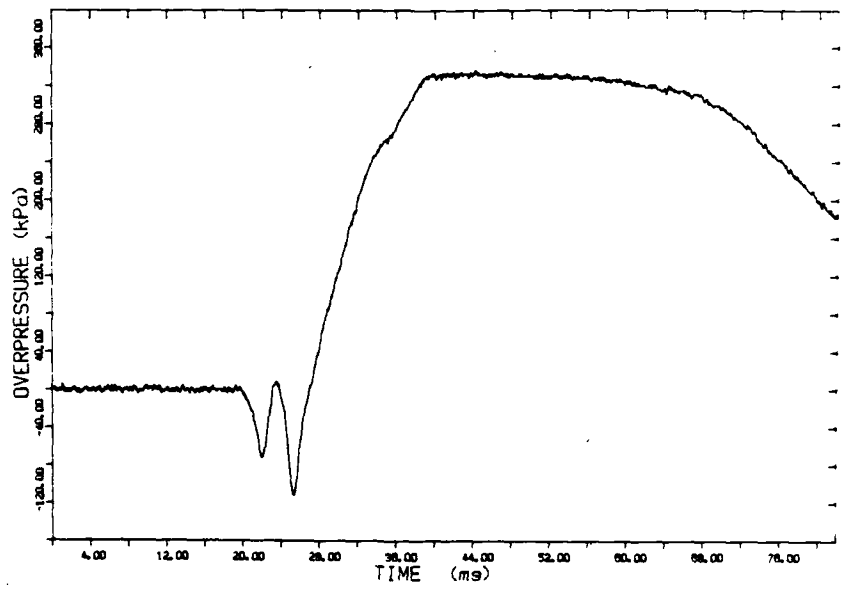

FIGURE 10 Smoothed pressure-time record from ground shock Event G1. d = 1.5 m (N). Record clipped.

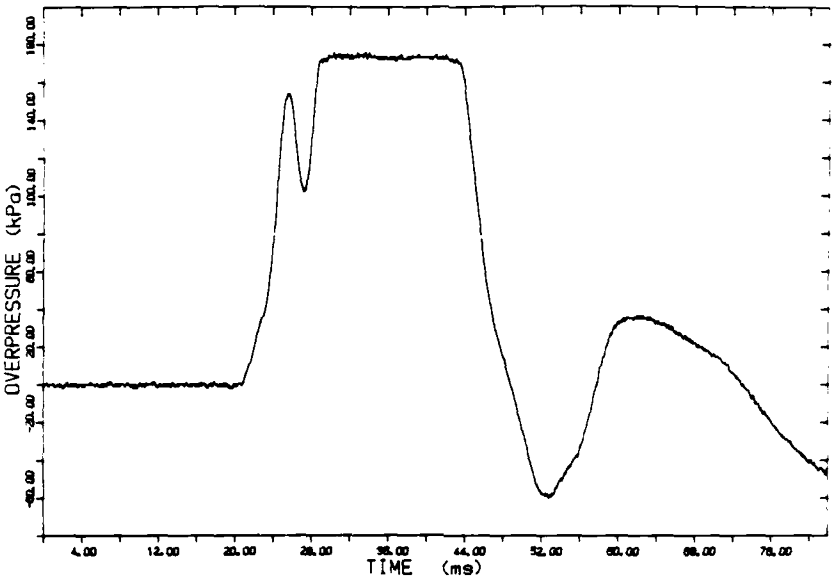

FIGURE 11 Smoothed pressure-time record from ground shock Event G1. d = 1.8 m (S). Record clipped.

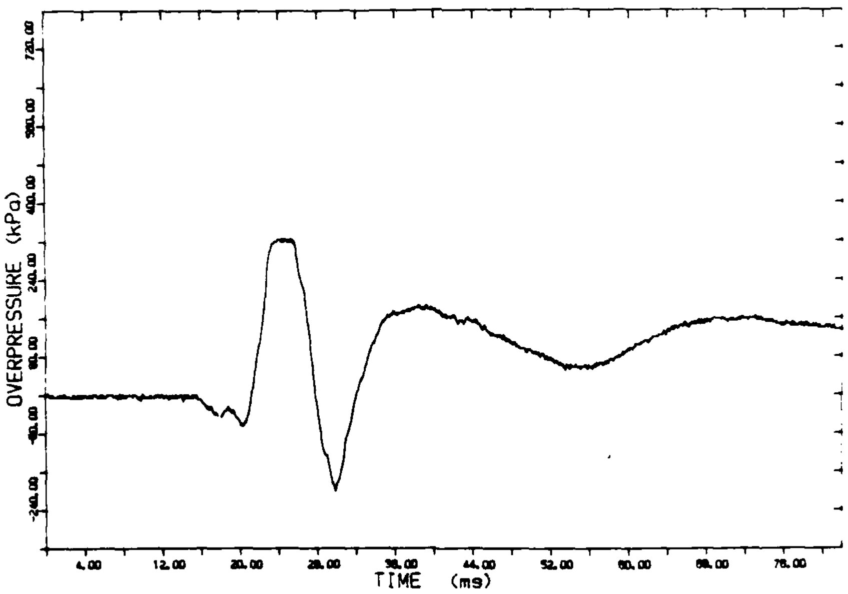

FIGURE 12 Smoothed pressure-time record from ground shock Event G2. d = 1.5 m (N). Record clipped.

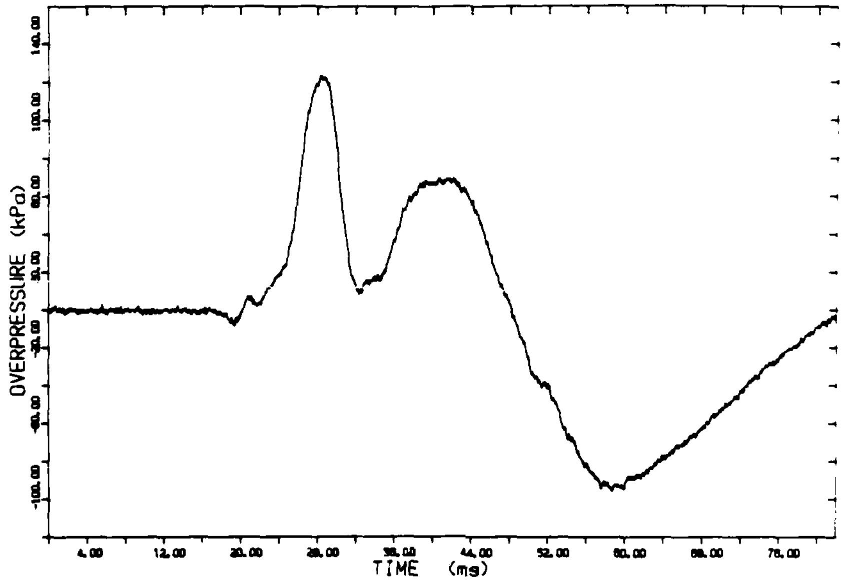

FIGURE 13 Smoothed pressure-time record from ground shock Event G2. d = 1.8 m (S).

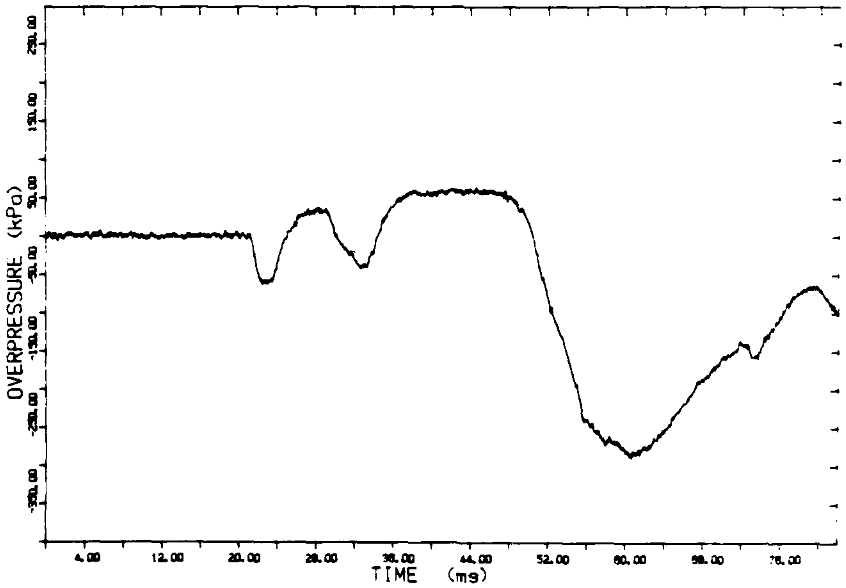

FIGURE 14 Smoothed pressure-time record from ground shock Event G3. d = 2.7 m (N).

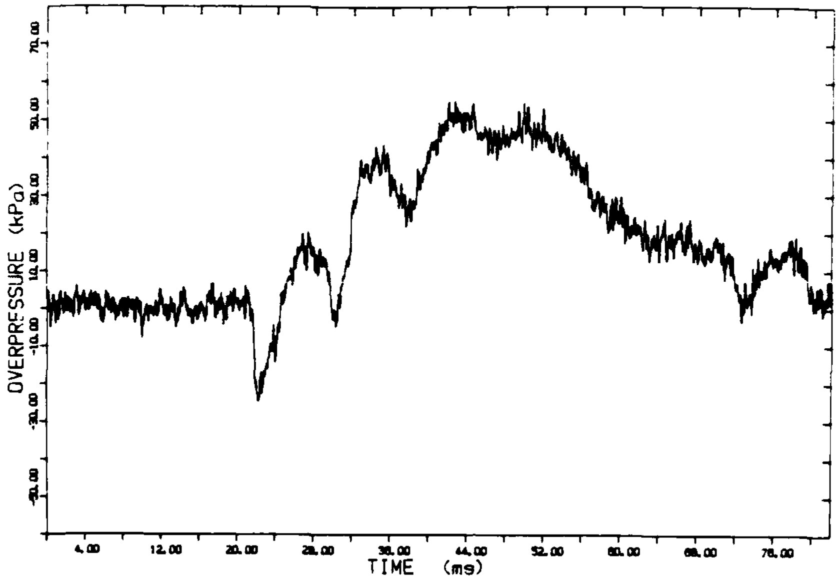

FIGURE 15 Smoothed pressure-time record from ground shock Event G3.
d = 2.7 m (W).

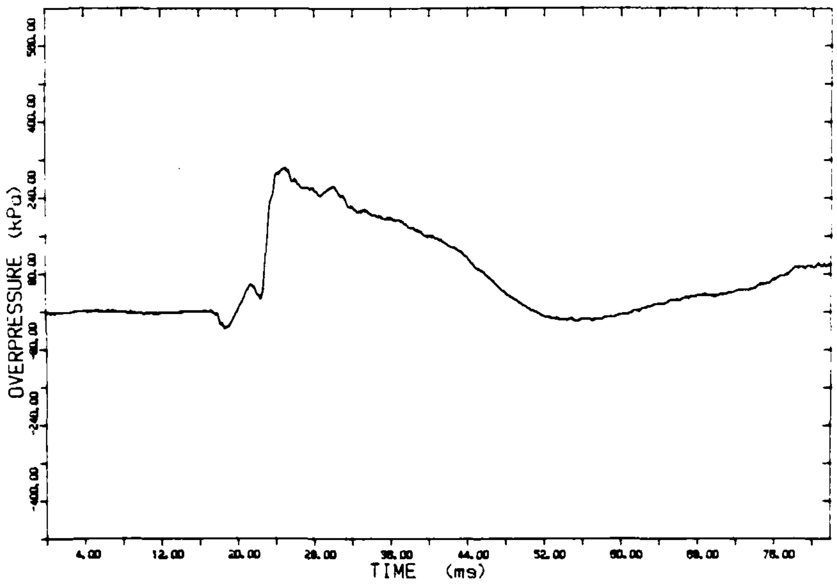

FIGURE 16 Smoothed pressure-time record from ground shock Event G3.
d = 1.35 m (N).

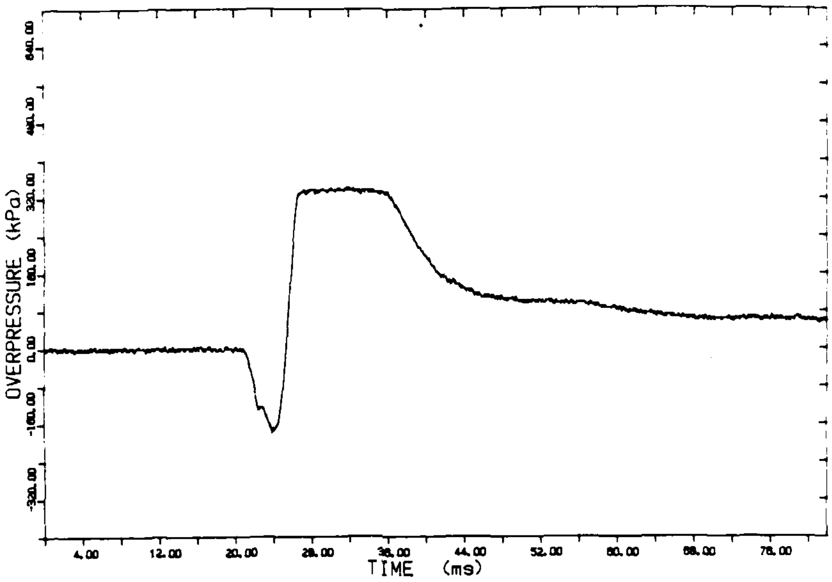

FIGURE 17 Smoothed pressure-time record from ground shock Event G4. d = 1.5 m (N). Record clipped.

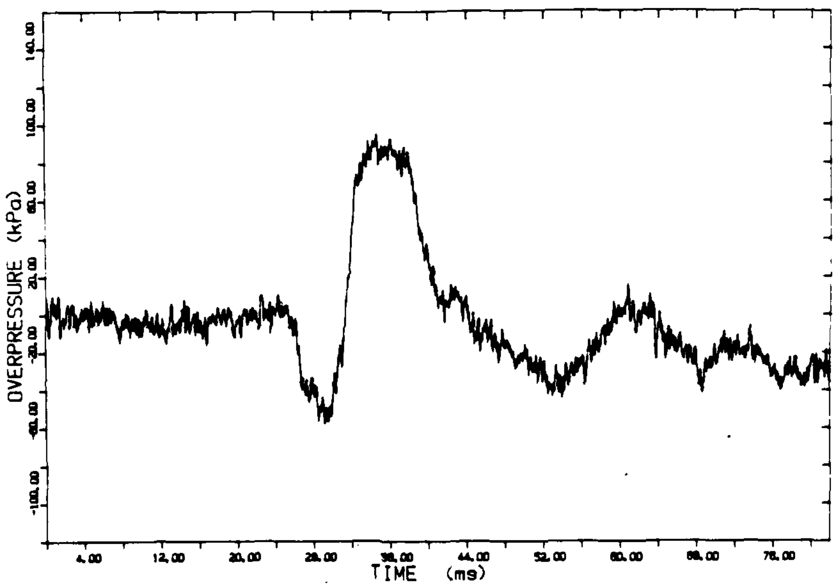

FIGURE 18 Smoothed pressure-time record from ground shock Event G5. d = 3 m (SE).

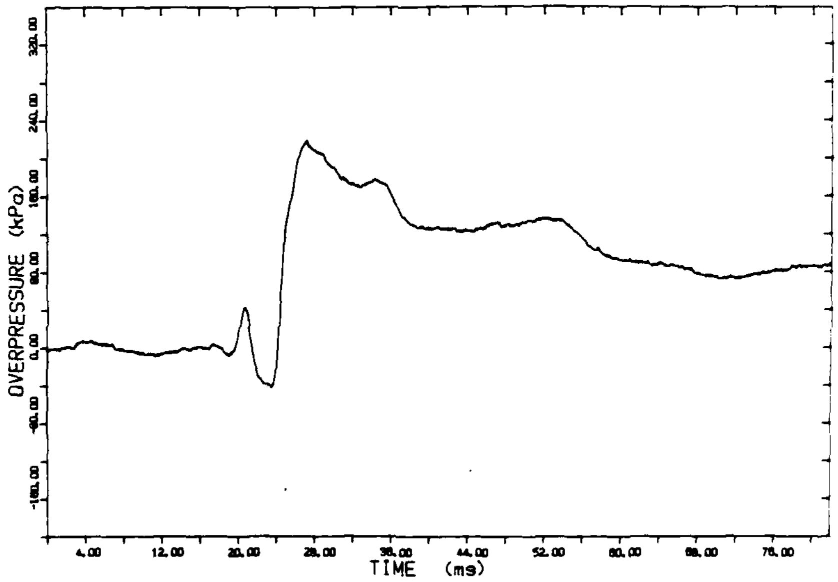

FIGURE 19 Smoothed pressure-time record from ground shock Event G5. d = 1.5 m (NW).

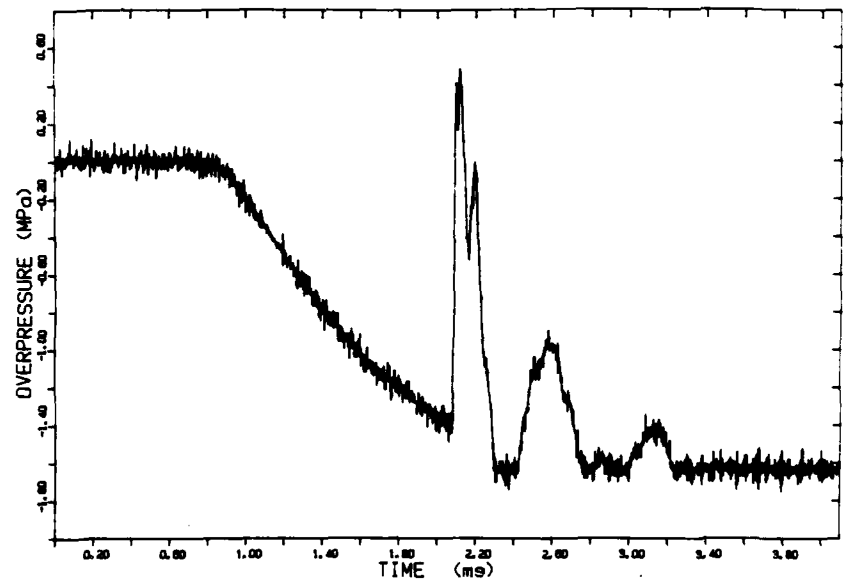

FIGURE 20 Pressure-time record from air blast Event A1. d = 1.5 m (NW).

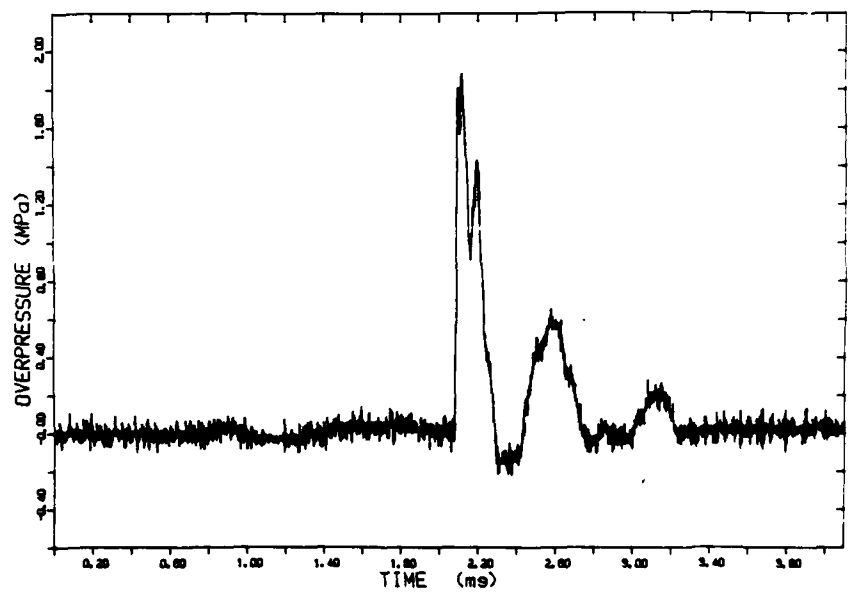

FIGURE 21 Pressure-time record from air blast Event A1. Data corrected for drift. d = 1.5 m (NW).

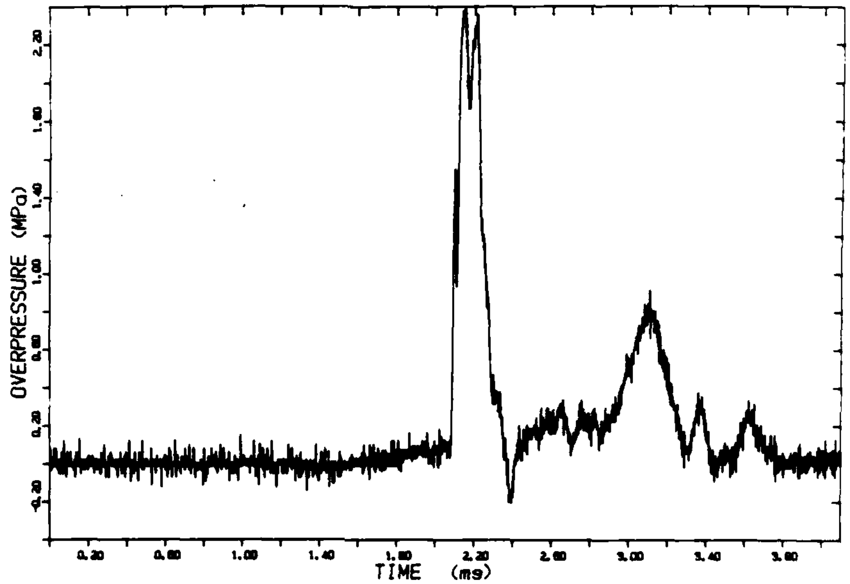

FIGURE 22 Pressure-time record from air blast Event A1. Data corrected for drift. d = 1.5 m (SE).

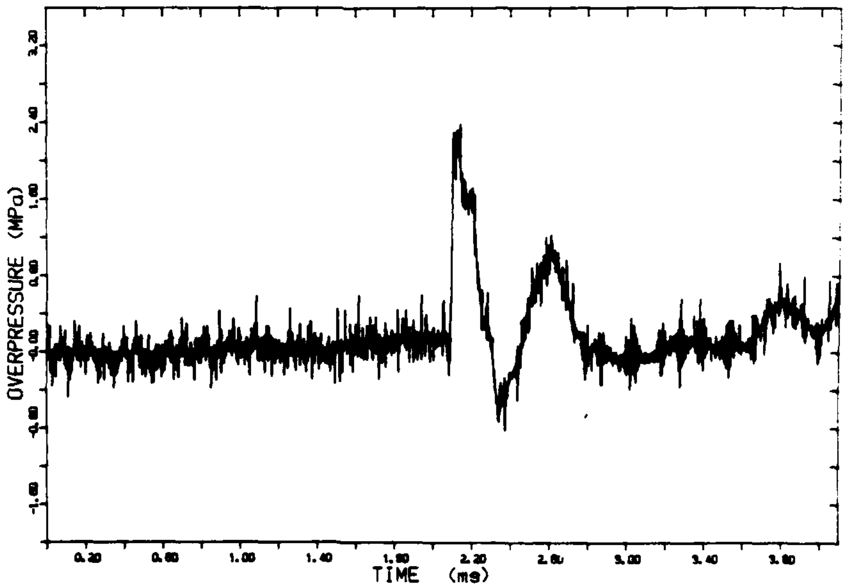

FIGURE 23 Pressure-time record from air blast Event A2. Data corrected for drift. d = 1.5 m (NW).

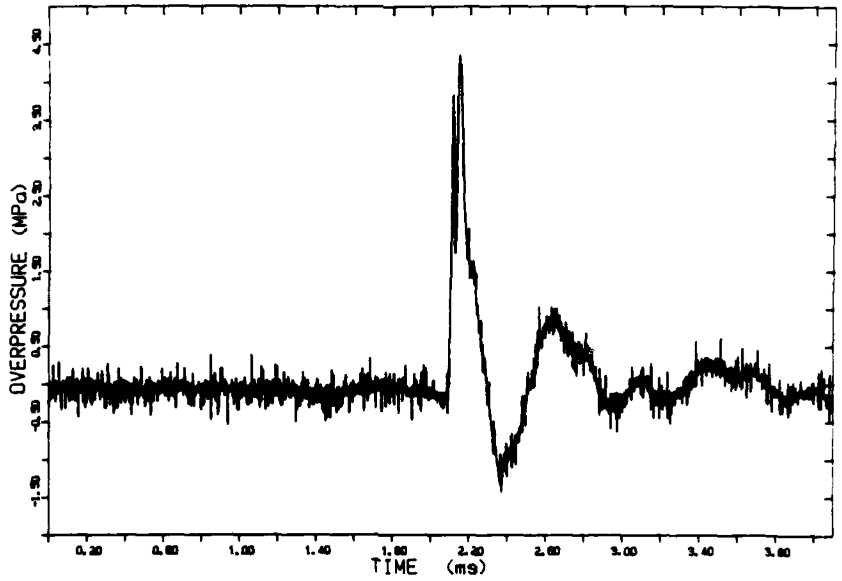

FIGURE 24 Pressure-time record from air blast Event A2. Data corrected for drift. d = 1.5 m (SE).

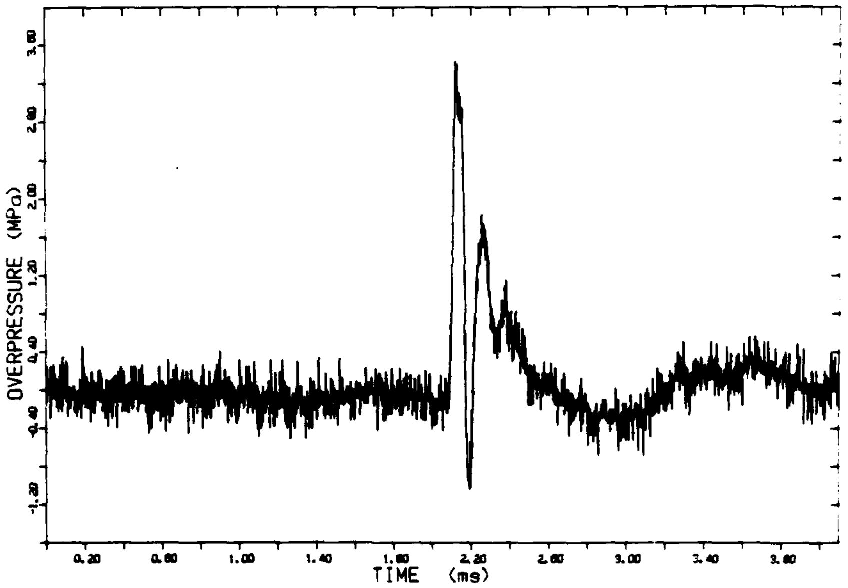

FIGURE 25 Pressure-time record from air blast Event A3. Data corrected for drift. d = 1.5 m (NW).

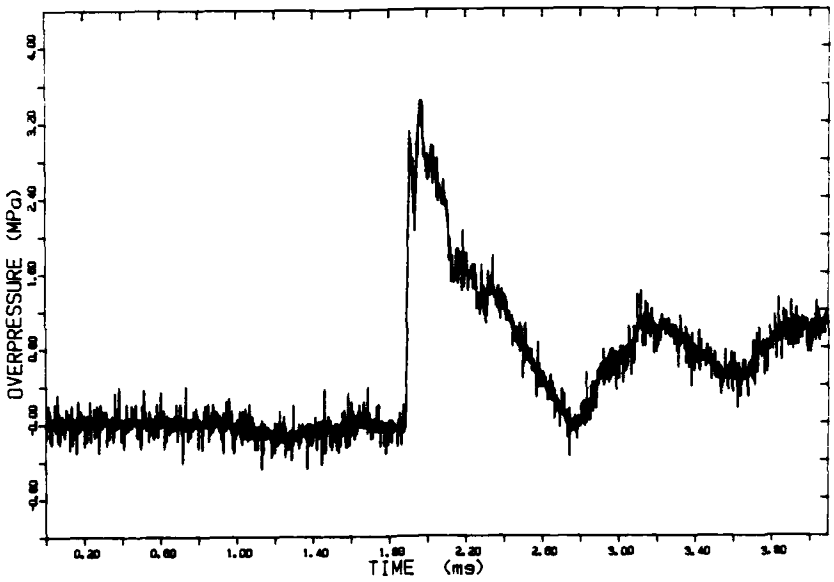

FIGURE 26 Pressure-time record from air blast Event A3. Data corrected for drift. d = 1.5 m (SE).

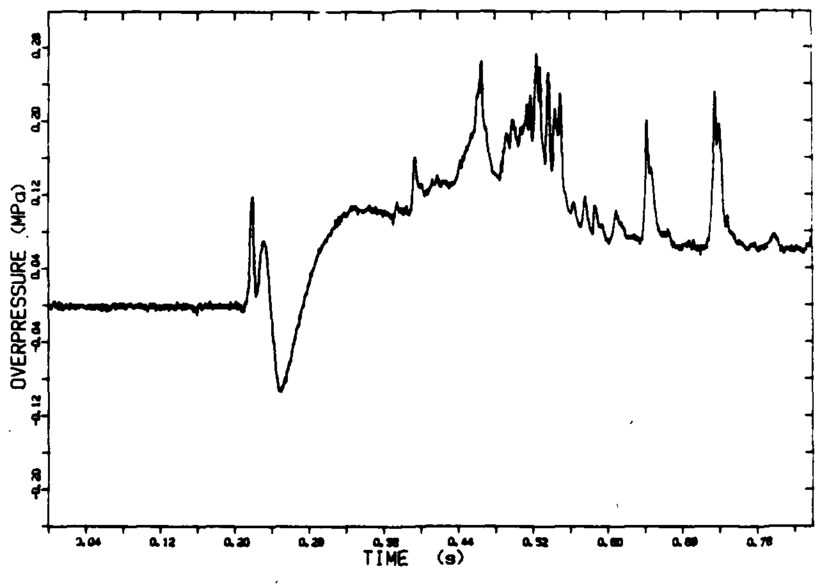

FIGURE 27 Smoothed pressure-time record from ground shock Event G2. d = 1.8 m (S) Long time-scale.

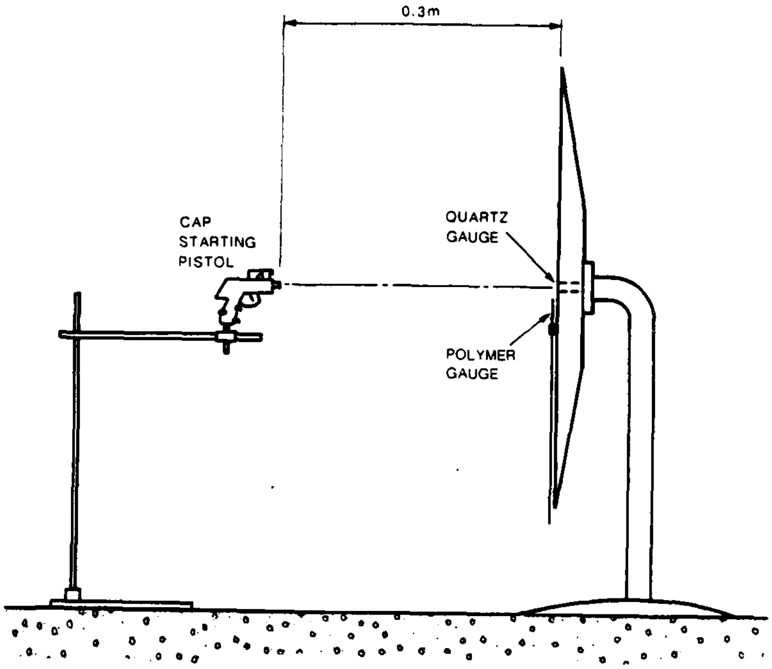

FIGURE 28 Schematic diagram of gauge mounting for laboratory investigations.

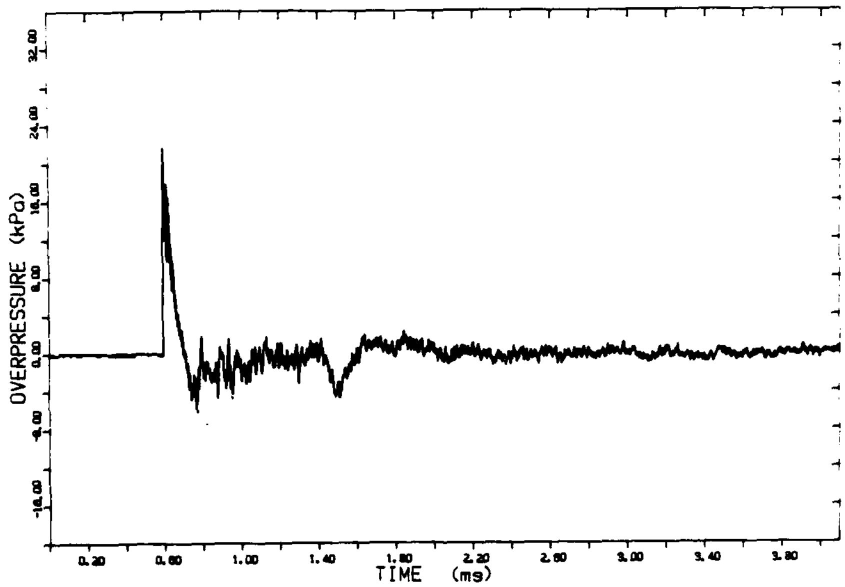

FIGURE 29 Pressure-time record obtained during laboratory investigations. Quartz pressure gauge. Event L1.

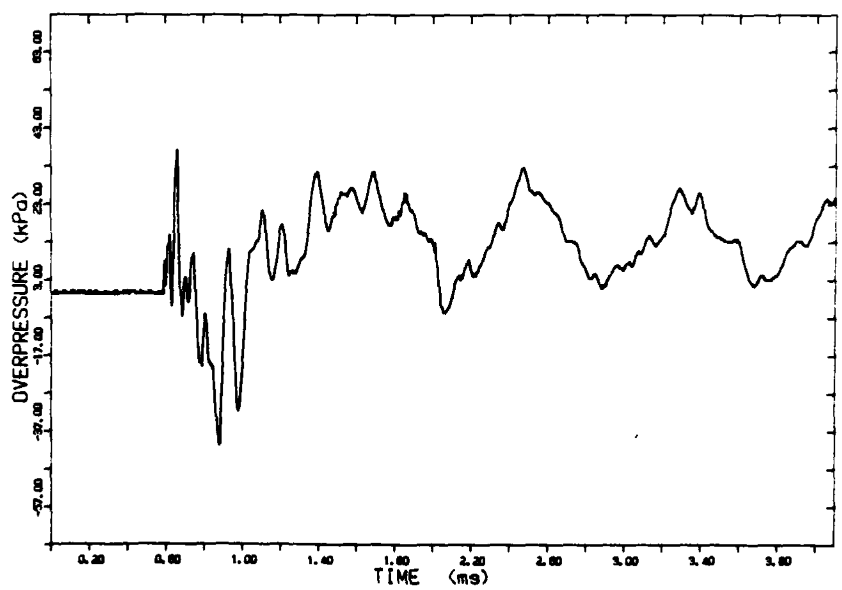

FIGURE 30 Pressure-time record obtained during laboratory investigations. Polymer gauge secured with adhesive tape. Event L1.

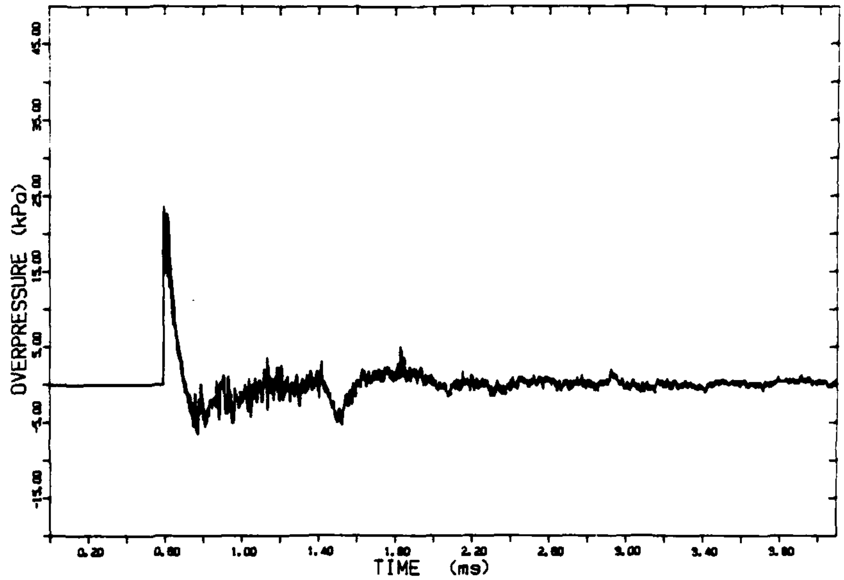

FIGURE 31 Pressure-time record obtained during laboratory investigations. Quartz pressure gauge. Event L2.

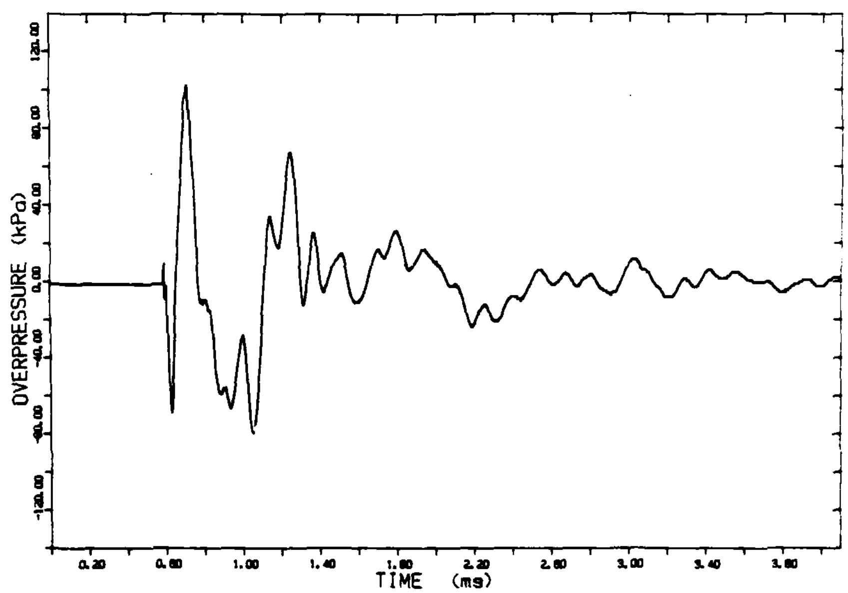

FIGURE 32 Pressure-time record obtained during laboratory investigations. Polymer gauge secured with double sided foam tape. Event L2.

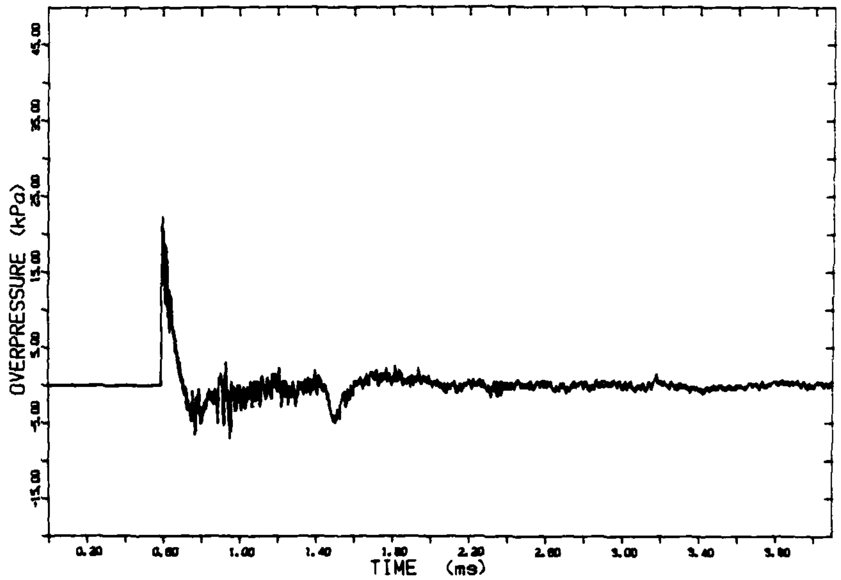

FIGURE 33 Pressure-time record obtained during laboratory investigations. Quartz pressure gauge. Event L3.

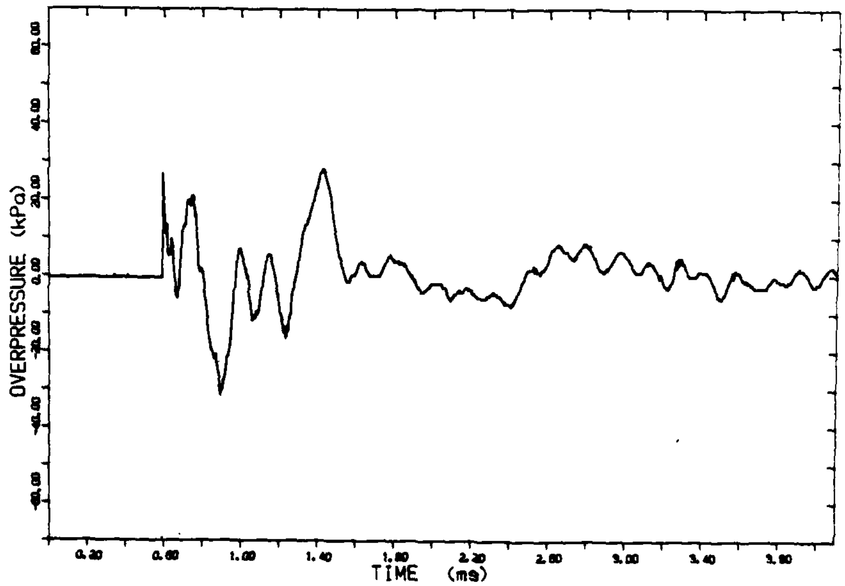

FIGURE 34 Pressure-time record obtained during laboratory investigations. Polymer gauge bedded in Silicone. Event L3.

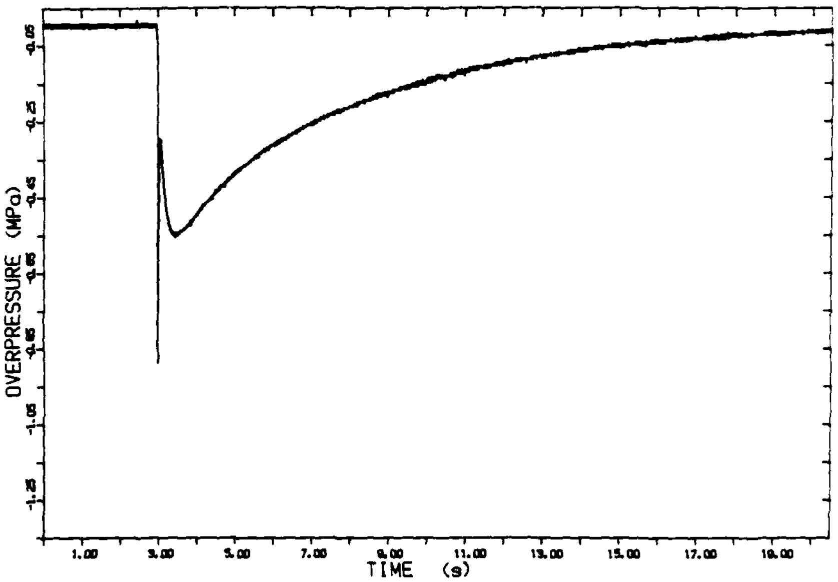

FIGURE 35 Equivalent pressure-time record obtained using photographic flash-gun. No filter.

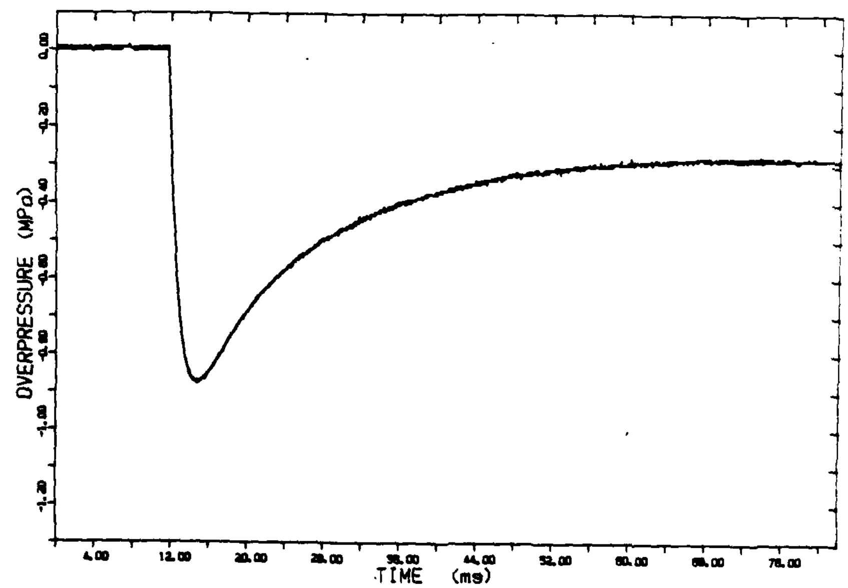

FIGURE 36 Equivalent pressure-time record obtained using photographic flash-gun. No filter.

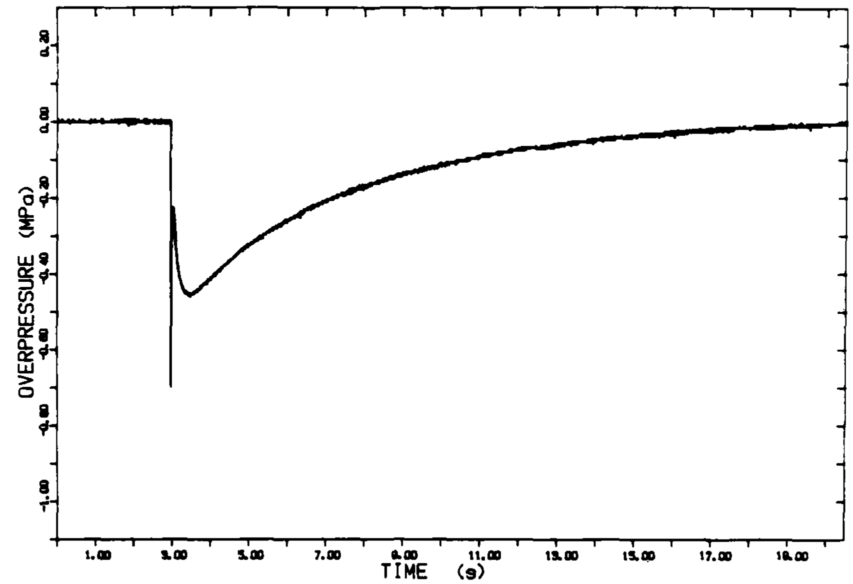

FIGURE 37 Equivalent pressure-time record obtained using photographic flash-gun. Filtered by 25 mm perspex.

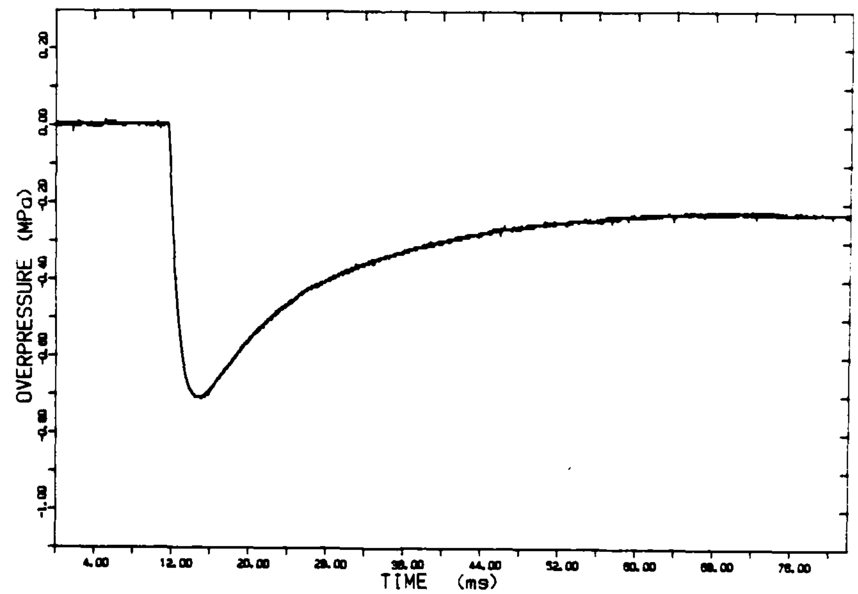

FIGURE 38 Equivalent pressure-time record obtained using photographic flash-gun. Filtered by 25 mm perspex.

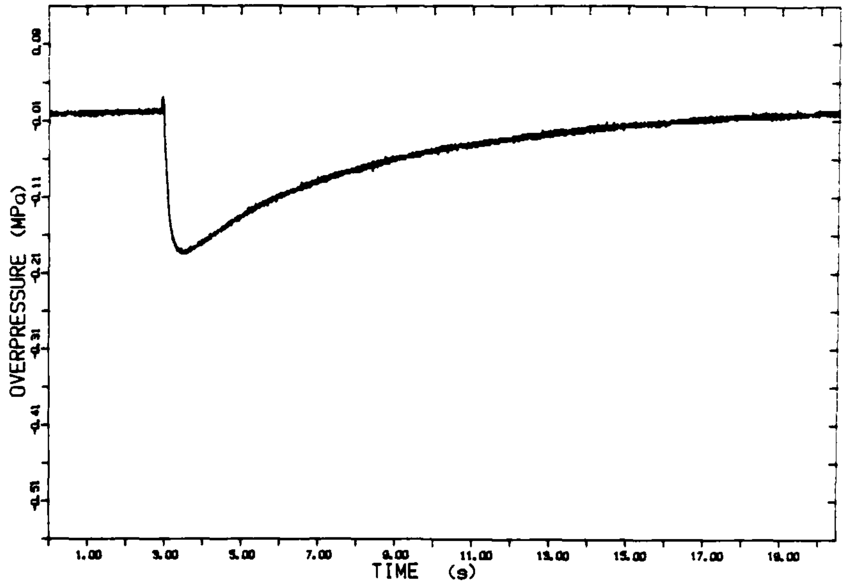

FIGURE 39 Equivalent pressure-time record obtained using photographic flash-gun. Filtered by copper sulphate solution.

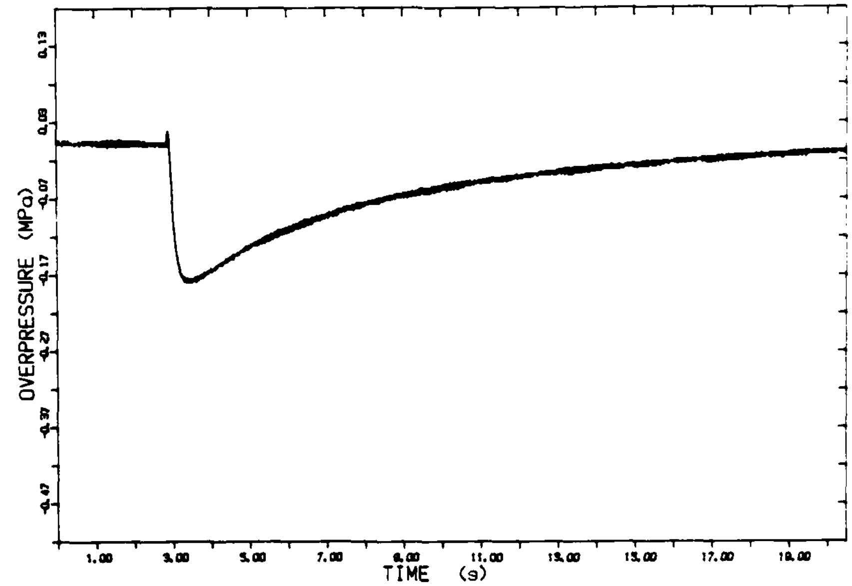

FIGURE 40 Equivalent pressure-time record obtained using photographic flash-gun. Filtered by 25 mm perspex and copper sulphate solution.

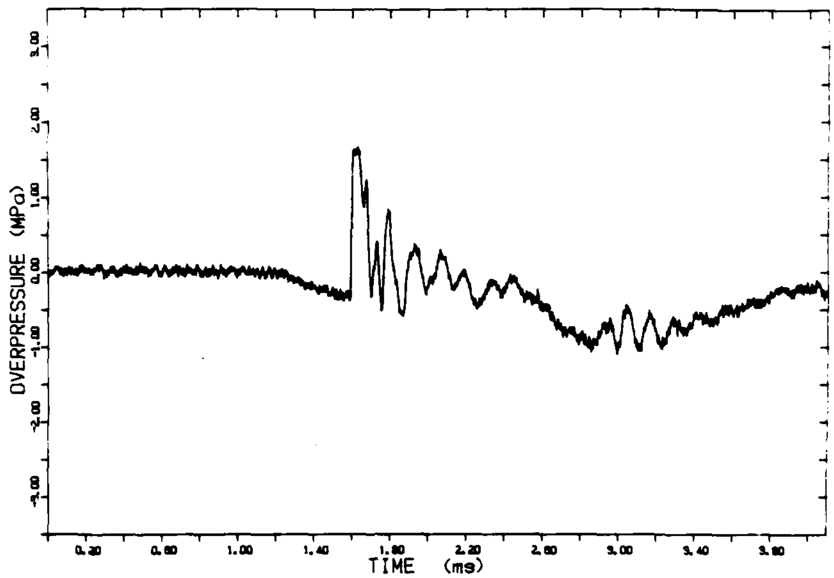

FIGURE 41 Pressure-time record obtained during laboratory investigations. Polymer gauge with no covering. Event L4.

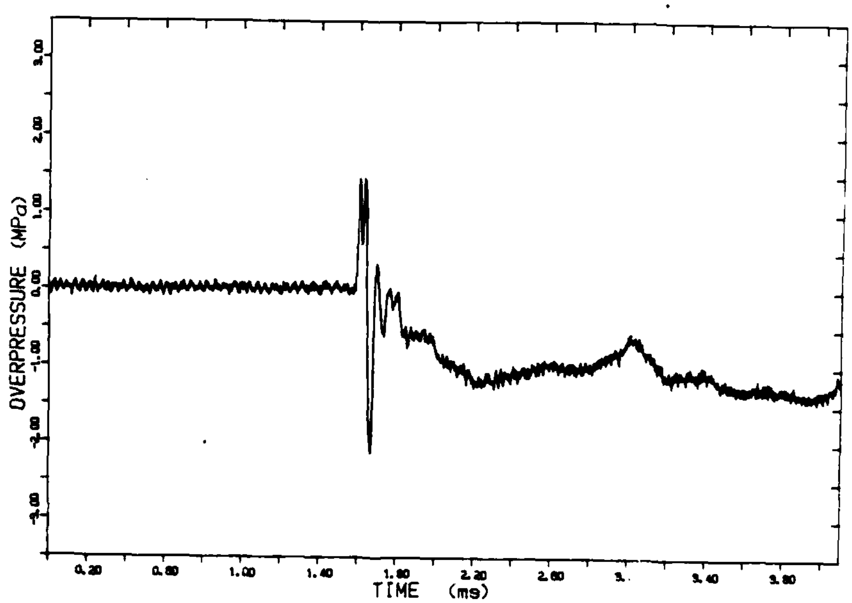

FIGURE 42 Pressure-time record obtained during laboratory investigations. Polymer gauge covered with three layers of aluminised mylar. Event L5.

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ABSTRACT

A site investigation survey was conducted during November 1986 as a preliminary requirement for the drafting of a trials plan associated with the proposed Australian Structures Response Evaluation Trials. The site near Woomera, South Australia was formerly used by the European Launcher Development Organization during the 1960's. Ground shock and air blast measurements were conducted during the survey. This report details the instrumentation and the techniques used for making these measurements.

An investigation into the response of the piezoelectric polymer transducers used during the survey is described and the results reported.

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